Experimenting with coal combustion products as liners for treatment wetlands: 2002 report

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Introduction

Engineered wetlands provide natural alternatives for wastewater treatment, storm water storage, and flood diversion. A new market is evolving around the use of natural landscapes as beneficial and cost effective treatment alternatives. Recent advances in wastewater treatment follow this trend to avoid more typical chemical and energy intensive methods. Research attempting to characterize and quantify the range of nutrient and pathogen removal has resulted in a highly variable range of efficiencies (Werker *et al.*, 2002). A perceived niche for small-scale decentralized wastewater treatment wetlands is calling engineers to develop more predictable and sustainable solutions to water quality management.

Current research at the Olentangy River Research Park applies the physical assets of clean coal technology products to meet needs in tertiary wastewater treatment for the removal of Phosphorus. The coal combustion product Flue Gas Desulfurization (FGD) material is being used to create low-permeability liners for treatment wetlands. FGD is a solid form of sulfur oxides that is precipitated by lime scrubbing techniques in coal-fired electric plants. Principally composed of sulfates and or sulfites, un-reacted lime and limestone, and fly ash, FGD material may fit well in the role of reducing Phosphorus in wastewater. Excess calcium in the FGD material can bind with Phosphorus and precipitate as hydroxyappatite.

This ash, historically treated as a waste product, can be engineered to achieve a range of strength characteristics (Butalia and Wolfe, 1999). Laboratory experiments on compacted and stabilized FGD, by Butalia and Wolfe (1999), achieved permeability coefficients lower than 1 $x10^{-7}$ cm s^{-1}. These findings encouraged field studies using compacted FGD material as liners for treatment wetlands at the mesocosm (1 m^2) scale (Ahn et al. 2001). Results from mesocosm experiments conducted in this laboratory found greater removal of total phosphorus and soluble reactive phosphorus in mesocosms lined with FGD material than unlined mesocosms (Ahn *et al*., 2001). In light of the findings published by Ahn *et al*., 2001 current research applies FGD-liners to constructed treatment wetlands at a pilot (13 m^2) scale over a three-year period (2000-2003) to test the hydrologic and ecological efficacy of FGD-liners compared to earth clay-liners in wetlands. Objectives to meet that goal include (1) investigating the effect of FGD liner on water quality, plants and soil chemistry, (2) Examining the hydrologic efficacy of FGD lines compared to clay liners in wastewater treatment wetlands, and (3) addressing considerations of scaling in pilot research.

Methods

Mesocosm construction

The pilot scale experiments are being carried out in four created wetlands at the Olentangy River Wetland Research Park (Mitsch et al., 1998) in Columbus, Ohio, USA. Construction on the wetlands began in March 2000; the four basins were excavated and lined with HDPE plastic liner material. The HDPE serves as an impervious liner between the wetland and the underlying soil and water, it can capture and contain any water that may leach through the experimental liners. One foot of number eight Ashtoe gravel was arranged in a trench at the bottom of each basin and covered with Geonet fabric to form a leachate collection system. Two extensions of PVC pipe extend from the gravel-filled trenches of the leachate collection up above the ground surface, and are used to collect samples of leachate water. These leachate collection wells are arranged at both the inflow and outflow sides of each basin. Dewatered and treated FGD product was compacted into a six inch layer above the Geonet fabric in the two treatment basins, and local clay soil was re-compacted into a six inch layer similarly in two control basins. The Geonet layer kept the respective liner materials from mixing into the interstitial spaces of the leachate collection system. Both FGD-lined and Clay-lined basins were filled with two feet of local topsoil.

Flow systems were installed July 2000. A Teel® 4RJ42 pump draws water from the near-by Olentangy River into four 1027L drums. A network of poly vinyl chloride (PVC) piping carries the water from each drum (1-4) to its' respective basin (1-4). A 2-inch ball valve at the head of each inflow pipe allows control of inflow rates by loosening or tightening. Inflow water disperses through T-branch end pieces before passing into each basin to avoid erosion effects on soil at the inflow. Standpipes control the outflow of each basin allowing waters above 15 cm to drain out through an underground pipe into a landscape trench. The outflow trenches lye below the elevation of the basins so exiting waters return to groundwater. Staff gages display the water level near each basins outflow.

Two species of bulrush were planted in the topsoil of each basin, July 7, 2000. Twenty root bundles of *Scirpus americanus* were planted near the outflow of each basin, and twenty root bundles of *Schenoplectus tabernaimontani* were planted near the inflow of each basin. Both rhizomatous perennials are common in shallow marshes, and fluoresce June-September.

Data Collection and Analysis

Hydrology

Hydrologic induction began April 23, 2001; inflow valves were manipulated to achieve a hydrologic loading rate (HLR) in the range of 10-15 cm/week. The first week of the study FGD-lined basins showed a shorter retention time than clay-lined basins by 30%. During the remainder of the study period (2001-2003) water level was recorded three days a week, in each basin, both prior to loading and after loading.

The leachate water accumulated in the collection system was purged on alternate months for year 2001. The following two years (2002-2003) leachate was purged on alternate weeks as more leachate was accumulating than expected. During November 3-12, 2002water levels inside the leachate collection wells were monitored daily with a handheld water level monitor.

The pump system was dismantled during the freezing months of November-March, and reassembled in early spring for each year of the study. On June 3, 2003 the outflow piping for basins 2 (clay-lined) and 3 (FGD-lined) were examined for leaks; the standpipes in both were refitted with adhesive. On June 7, 2002 and July 1, 2003 rodent holes on the perimeter of the basins were filled with local topsoil and manually compacted.

Water quality

On site water quality data was collected at the inflow, where waters from each of the four drums enter respective basins, and outflow where waters exit the standpipe. A handheld YSI 600XL water quality monitor manually inserted into the overlaying waters of each basin for 1 minute computed parameters: temperature, conductivity, DO, and pH. 500mL samples of surface water were collected at the inflow and outflow of each basin in years 2001 and 2002. Analysis of these overlaying waters revealed disproportionately high sediment content in inflow samples collected at lower water levels. In 2003 sampling holes were drilled into the PVC pipes leading to the inflows of each basin; surface water samples were then collected just prior to exiting the pipe at the inflow of each basin. The method for collecting water at the outflow remained the same throughout the study.

Surface water samples were refrigerated at 0ºC for no more than 20 days until analysis. Two categories of sub-samples were prepared from the field-collected samples: Inorganic and organic. Organic samples were preserved by adding 0.5ml of H_2SO_4 to 100ml of sample and frozen for no more than 10 days. Thawed samples were examined for Total Phosphorus concentration by spectrophotometric analysis using a Lachat 8000 series FIA+. Inorganic samples were filtered through 0.5 micron cellulosic filters, and the solvent digested in a Lachat block digester BD-46 according to the Quik Chem® method (Lachat Instruments, 2000). Cooled samples were examined for SRP concentration using the Lachat spectrophotometer.

Nutrient simulation

Simulated wastewater will be added to the inflow waters leading to the four experimental basins June 5, 2003. Hi-yield® triple super Phosphate containing 0-45-0 Phosphorus Oxide (P_2O_5) will be mixed into river water at the drums to mimic secondarily treated wastewater 2-3mg-P/L. The percentage of elemental Phosphorus (P) in P_2O_5 has been calculated using Equation 1,

$$\frac{SgP}{L} \times \frac{10gP_2O_5}{1gP} = \frac{IgP}{L} \qquad (1)$$

where,

S= mass of nutrient needed to achieve desired inflow concentration

I= mass of fertilizer added to simulate waste water.

Water quality data were collected as described above at the inflow and outflow of each basin.

Vegetation

Number of stems for both of the planted species was recorded twice a month throughout the duration of the study. Stem length was measured for 40 random individuals of both planted species. Number of flowers was recorded as a ratio out of 20 to make inferences about plant maturation and species fecundity. In each basin four 1-m2 areas were harvested August16, 2001 and September 15, 2002, the final harvest is scheduled for September 15, 2003. Harvested plants are separated according to species, and weighed in bundles. A sub-sample of each bundle is dried at 60ºC in a forced air oven for no more than two days, weighed, and ground to pass a 2mm sieve. Ground plant tissue is analyzed for all major elements using spectrophotometric analysis by ICP. Species not planted during the study established in the basins increasingly over the three growing seasons of the study; these invasives were identified and included in total biomass harvesting. The flowering bodies were removed from the highly aggressive *Typha* sp. to suppress the spread to adjacent mesocosms.

Soil

Local topsoil was sampled prior to completion of the basins in 2001. Local clay, used to line the control basins, and FGD used to line the treatment basins were sampled and analyzed. After the first growing season, soil cores were collected at four points thought the basins for analysis of topsoil after two years of inundation and contact with the respective liner materials. Soil samples were air dried near 30ºC, and ground to pass a 2mm sieve. Complete element analysis by ICP spectrophotometer was conducted after microwave 3051 digestions, and according to the EPA standard method.

Leachate water

At the onset of the study water was not expected to leach through either liners materials notably, the leachate collection system was more of a precautionary devise, and allowed leachate to be sampled prior to passing into groundwater. During the study the leachate collection systems were estimated to have held 200L per 30 days of basin inundation. The methods for purging the leachate collection system were modified accordingly to remove water regularly and collect fresh sample of leachate. An Isco 150 portable pump was used to draw 500mL water samples from each leachate well weekly. Excess water was drawn for sampling with the YSI 600XL water quality monitor. Leachate samples were analyzed similarly to the above ground samples using the Lachat Quik Chem® method.

Preliminary Results

Hydrology data from the first two years of the study show that FGD-lined basins do not retain water as efficiently as clay-lined basins. Figure 1 gives the average water level for each of the four basins in 2001-2002. Water levels in the FGD-lined basins were consistently lower than clay-lined basins in 2001, and statistically lower in 2002. We suspect this trend is a result of either the mixture of FGD material used to make the liner or the method of compacting the liner. Alternatives mixtures have been reported by Butalia and Wolfe (1999). Lining technique was reported to be an important factor by Bower et al. (2000).

Surface water at the inflow showed surprisingly high standard error for the parameters measured in the field among the FGD-lined and clay-lined basins (Table 1a). This variance is expected to be due to sampling techniques described earlier. The modification of inflow water sampling techniques is expected to reduce this variation. Water quality data show no significant differences between FGD-lined and clay-lined waters at the outflow for 2001 and 2002 (Table 1b). For both clay-lined and FGD-lined basins the change from inflow to outflow shows that water is less turbid with slightly lower conductivity, this trend is typical in slow flowing wetlands.

Probably the most significant finding so far has been that wetland plant growth in the FGD-lined basins was significantly lower than wetland plant biomass in clay-lined basins at the end of the first two growing seasons (Table 2). This was somewhat unexpected and suggests that their either may be toxic effect of the liner getting into the vascular system of the plants or the water level changes are significant enough to cause this difference. There is some early indication that specific species may have greater success in FGD-lined wetlands.

Leachate samples in FGD-lined wetlands show significantly higher SO_4, S, Na, K, and Ca concentrations in the first full growing season (2002) (Figure 2). Most of

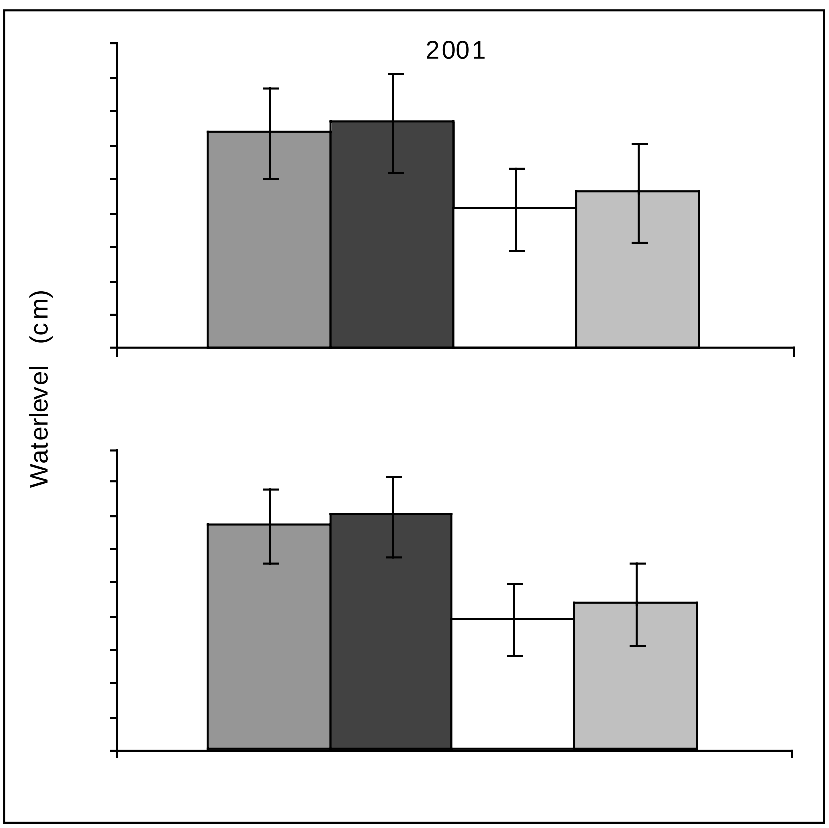

Figure 1. Average water levels in Clay-lined and FGD-lined basins for 2001-2002

Table 1a. Surface water quality for water at the inflow of the basins

	FGD-lined	Clay-lined
2001		
Conductivity (µS/cm)	579 ± 71	583± 52
PH	8.56± 0.43	7.81± 0.23
Turbidity (NTU)	23.42± 14.5	57.3± 34.4
2002		
Conductivity (µS/cm)	667± 11	663± 84
PH	7.50± 0.01	7.62± 0.16
Turbidity (NTU)	23.4 ± 4	57.2± 30

Table 1b. Surface water quality for water at the outflow of the basins

	FGD-lined	Clay-lined
2001		
Conductivity (µS/cm)	715 ± 127	584± 50
PH	8.76± 0.50	8.17± 0.22
Turbidity (NTU)	12.6± 6.0	38.7± 23
2002		
Conductivity (µS/cm)	647± 5.5	645± 6
PH	7.52± 0.02	7.58± 0.06
Turbidity (NTU)	12.6 ± 4.0	38.7± 28

Table 2. Average plant biomass (g-dry wt m-2) for indicator species in 2001 and 2002

	FGD-lined	Clay-lined
2001		
Scirpus americanus	5.8 ± 2.6	16.9± 5.6
Schenoplectous tabernaimontani	151.9± 13.4	197.1± 27.1
2002		
Scirpus americanus	160.8± 37.2	266.8± 76.7
Schenoplectous tabernaimontani	186.8 ± 55.3	208.7± 54.8

these elements, common to the FGD material, did not appear in the leachate until the second actual year of data. A possible weathering effect on the material is suspect, and will have to be validated with several measurements in the next few years of leachate quality. Leachate shows consistently higher B, a potential toxin to vascular plants, in FGD-lined ponds (Table 3). Leachate was also higher in pH and conductity in the FGD-lined ponds in both 2001 and 2002, reflecting the alkaline nature of the FGD material and the leaching that occurs when water passes through it.

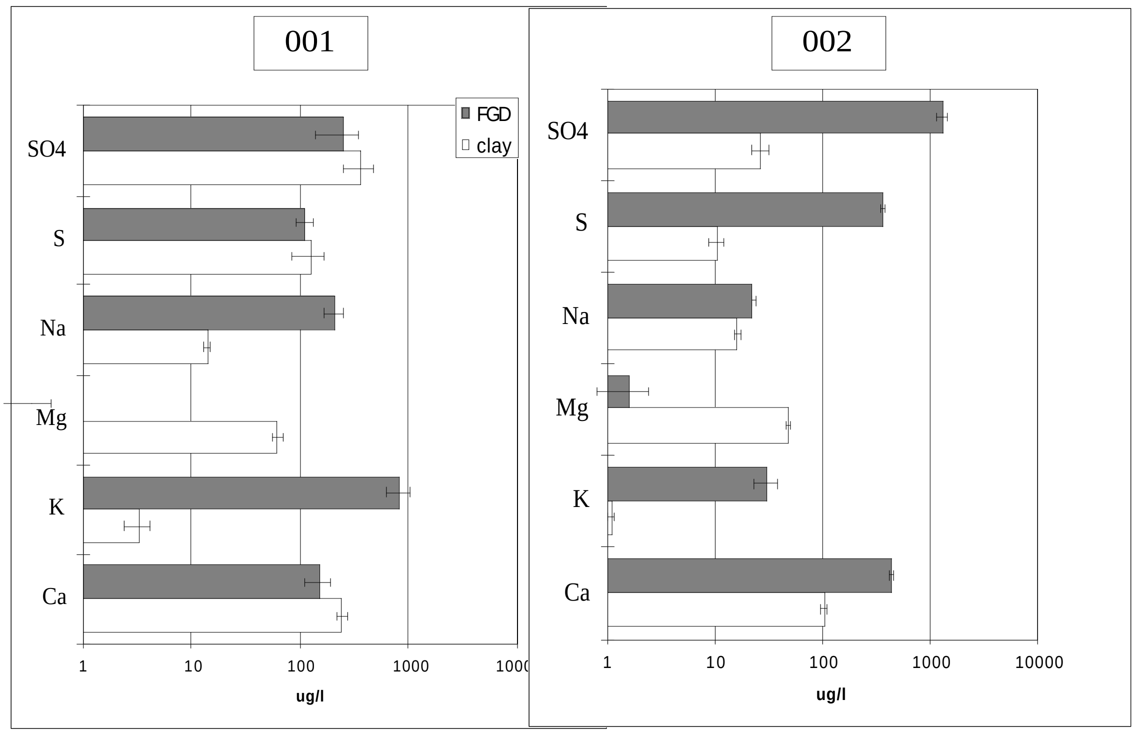

Figure 2. Element composition of leachate water in FGD and Clay wetlands for 2001 and 2002

Table 3. Leachate water quality for 2001 and 2002. Data is presented as an average and standard error or as the lowest threshold with out standard error.

	FGD-lined	Clay-lined
2001		
Conductivity (µS/cm)	1591 ± 232	1018± 89
PH	9.80± 0.28	8.08± 0.39
Turbidity (NTU)	10.13± 3.28	6.45± 0.81
B (µg/L)	0.15± 0.03	0.07± 0.01
2002		
Conductivity (µS/cm)	1620± 370	901± 89
PH	9.27± 0.08	7.16± 0.04
Turbidity (NTU)	13 ± 4	19± 5
B (µg/L)	1.5± 0.2	0.05

Conclusion

Retention time was lower in the FGD-lined basins than in the clay-lined control basins in 2002. The FGD mixture, as developed for this project, did not serve as an effective aquiclude to water movement.

There is no indication with river water that water quality is improved by either treatment or control at this pilot scale. Further study, and the application of Phosphorus should give greater insight into the ability of FGD-lined basins to reduce P concentrations.

There appears to be an effect of the FGD material on wetland plant biomass. Fewer *Scirpus americanus* stems were counted in the FGD-lined basins than the clay-lined basins, but *Schenoplectus tabernaimontani* was equally successful. There remains the question of whether this is due to toxicity of the FGD material or the differing hydrologic retention times.

Leachate is higher in the FGD wetlands than in the control wetlands for Na, K, S, and pH. Further investigation should uncover the expected duration of this effect.

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